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THE PRESCOTT SCALE, AN ENEMY ASSOCIATED WITH BRANCH
KILLING ON PONDEROSA PINE IN THE SOUTHWESTERN
UNITED STATES
(HEMIPTERA-HOMOPTERA)

by

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INTRODUCTION

A conspicuous type of branch injury or branch flagging, commonly known as "twig blight", has been observed for the past 20 or 25 years on ponderosa pine (Pinus ponderosa var. Scopulorum Englemann) trees in Arizona, particularly around the vicinity of Prescott. Forest Service correspondence files indicate that complaints pertaining to this tree disturbance have come in at rather definite intervals during this period.

Footnote, page 1.

Dr. F.C. Craighead, in charge of Forest Insect Investigations throughout the United States, directed much of the work and rendered helpful suggestions pertaining to the more technical problems encountered in this study. Mr. J. M. Miller, in charge of the Forest Insect Laboratory at Berkeley, California, had much to do with the general outlining and organizing of the problem and he gave personal encouragement and provided adequate support for the work.

Dr. Harold Morrison, of the Identification Division of the Bureau of Entomology and Plant Quarantine in the National Museum at Washington, D.C., was responsible for the assumption that the Matsucoccus scale was the cause of ponderosa pine branch killing at Prescott, Arizona. Furthermore, he outlined and actually participated in the initiation of preliminary field experimental work which was the basis for many opinions and conclusions developed subsequent to its initial investigation. For this and many other favors the present author is indeed grateful.

Through the courtesy of Messrs. J. C. Nave and J. C. McNulty of the United States Forest Service at Prescott, Arizona, special aid was given and equipment loaned for setting up experimental plots in the forest. Credit is also due to Mr. Victor O. Sandberg, Assistant Forester on the Prescott, who has made many valuable suggestions and rendered kind assistance at different times. Mr. Sandberg was responsible for aiding in setting up the large demonstration plots on the Prescott National Forest.

Professor G.F. Ferris of Stanford University has clarified certain scale insect morphological problems that have arisen during the course of this study.

To a field assistant, Mr. W.C. Reeves, who was engaged in the artificial infestation work, that was an absolute requisite for drawing definite conclusions, the writer is indebted.

The excellent pictorial plate showing the life history of this scale insect and the one diagraming the tanglefoot barrier studies have been prepared, under the writer's direction, by Mrs. Frieda Abernathy.

The actual correspondence having to do with this tree situation has been assembled by Mr. Victor O. Sandberg, Assistant Forester on the Prescott, and is included in a memorandum of November 30, 1938 entitled, "Compilation of File Correspondence on Twig Blight up to the Year 1930." This memorandum also makes available information on the progress of twig blight throughout these years and up to 1933. It includes verbatim all sentences, paragraphs and full letters or memos which had any bearing whatsoever on the subject at hand.

The first statements obviously referring to this tree condition appear in a letter written from Poland, Arizona, on April 8, 1911, by Mr. George R. Yorke, Assistant Forest Ranger, to the Forest Supervisor at Prescott, Arizona. Mr. Yorke was reporting upon a barkbeetle infestation near Mt. Union, but certain descriptions in his letter obviously refer to a branch injury on living trees. Apparently assuming that this was due to some insect, his letter states:

"This insect which appears as soon as the weather turns warm, along in May, confines its work entirely to the Yellow Pine.***While a majority of these trees are still alive the foliage is very scant.***In most of the trees there has been some new foliage put on but very little compared with the original cover; in a very few cases the younger trees have nearly recovered."

Other correspondence written during 1918 likewise pertains to this branch injury on ponderosa pine. The letters were written by Mr. E. G. Miller, Forest Supervisor on the Prescott, and Mr. Ralph Hopping who was then National Forest Examiner. This correspondence will not be cited here because the contents of these letters are so unquestionably suggestive of the flagging condition.

During 1933 there was a season of epidemic branch flagging so serious that the residents as well as the Forest Service officers at Prescott became quite alarmed. The year following (1934) also marked a season of intense flagging. On the assumption that the condition might be a disease, and that the apparently virulent organism or organisms might be foreign and possibly a threat to the pine stands of the southwest, the Bureau of Plant Industry, Division of Forest Pathology immediately began extensive investigations. Furthermore, the Division of Forest Pathology recommended eradication which consisted of cutting the dead and dying branches from flagged trees, these branches being later dumped into small piles and burned. CCC labor, under the Forest Service supervision, was employed in this extensive eradication program.

On May 16, 1935, Mr. J. M. Miller, Senior Entomologist in charge of the Forest Insect Laboratory at Berkeley, California, collected twigs from ponderosa pine at Prescott, Arizona that were heavily infested with what appeared to be a sucking insect (Hopkins' No. 21189). These infested branches were sent to Washington, D.C. to Dr. F. C. Craighead, in charge of Forest Insect Investigations throughout the United States. These were subsequently referred to Dr. Harold Morrison, scale expert of the Bureau of Entomology and Plant Quarantine, Division of Insect Identification in the National Museum at Washington, D.C., who immediately recognized the insects as a species of Matsucoccus scale of the family Margarodidae. Later, during January 1936, Dr. Ross W. Davidson, of the office of Forest Pathology, observed these scale bodies on flagged branches, and it was at first thought that they were some kind of fungus spores. Dr. Davidson was not sure that these bodies were insects, and so infested twigs were sent to Dr. Craighead for an examination. Dr. Craighead recognized them as apparently the same species of scale that he observed on the twigs Mr. Miller sent in during 1935. Davidson's infested twigs were referred to Dr. Morrison who identified the insects as the same species of Matsucoccus found on the twigs sent in the previous year. This scale insect, by reason of its consistent association with flagging in samples collected by Forest Pathology, was a subject of suspicion as a possible factor in the development of the flagging injury. An investigation of the scale, later described as Matsucoccus vexillorum Morrison,⁽¹⁾ was, therefore, initiated by the Bureau of Entomology and Plant

(1) 1939. Morrison, H. Descriptions of new species of Matsucoccus. (Hemiptera: Coccidae). Ent. Soc. Wash., Proc., 41:1-20.

Quarantine in January, 1936, and continued during the seasons of 1937, 1938 and 1939 which are the basis of the present report.

RELATION OF INSECTS TO FLAGGING INJURY

In April, 1934, the Bureau of Entomology and Plant Quarantine received copies of correspondence from the Forest Service calling attention to the abundance of stem infesting aphids on the Prescott areas and suggesting the possibility that these insects were in some way associated with the prevalence of flagging. This was followed up by a study by A. S. West of the Bureau of Entomology and Plant Quarantine, Forest Insect Division, during June and July, 1935, to determine what part, if any, the aphids might play in the conditions found near Prescott. The aphid infestation had largely disappeared when this study was started and West's report shows that such evidence as could be secured indicates that the feeding habits of the aphids do not cause injury to the stem tissues resulting in lesions or flags.

Certain species of the coccid family Margarodidae have been reported by various authors as inflicting considerable injury on economic plants. The cottony cushion scale, Icerya purchasi Maskell, has attained a tremendous notoriety as a pest since its initial introduction into California about 1870. Other genera of reported economic importance include some Margarodes attacking grapevine roots in South Africa and South America; Xylococcus causing damage to the bark of canoe birch in the Great Lake region of North America; a number of species of Drosicha injuring a variety of economic plants in the eastern Asiatic region from India to Japan, and so on.

Several species of Matsucoccus are known definitely to cause injury to pines. Matsucoccus acalyptus Herbert has been reported as early as 1921⁽²⁾ as doing damage to single-leaf pinon (Pinus monophylla) in Idaho,

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- (2) 1921. Herbert, F. B. The genus Matsucoccus with a new species. (Hemip.-Homop.). Ent. Soc. Wash., Proc. No. 1, 23; page 22, paragraph 3.
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and the present author observed this same species causing extensive defoliation to Pinus edulis on the south rim of the Grand Canyon in Arizona during the 1938 summer season. In 1928 Morrison⁽³⁾ reported one species of Matsu-

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- (3) 1928. Morrison, H. A classification of the higher groups and genera of the coccid family Margarodidae. U.S. Dept. Agr. Tech. Bull. 52: 1-240. Illus.
-

coccus as causing gall-like pits on pine twigs, and doing appreciable damage to some ornamental plantings. This species was later described by Morrison as Matsucoccus gallicolus and its host was recorded as Pinus rigida. More recently other species of Matsucoccus have been observed causing both stem and foliage injury. These are, Matsucoccus paucicicatrices Morrison, on sugar pine in California; Matsucoccus fasciculensis Herbert⁽⁴⁾ on digger

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- (4) 1919. Herbert, F. B. A new species of Matsucoccus from pines in California. (Hemip.-Homop.). Ent. Soc. Wash., Proc. 7:157-161.
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and ponderosa pines in California; and Matsucoccus bisetosus Morrison, M. californicus Morrison on ponderosa pine in California. Injury to twigs and stems somewhat resembling Prescott flags are not uncommon in forest areas.

The relation of the scale, Matsucoccus vexillorum Morrison to flagging injury in the areas around Prescott, Arizona will be shown in later sections of this paper.

GENERAL DESCRIPTION OF FLAGGING INJURY

Damage to the ponderosa pine branches is usually noticeable first in the early spring. Flagging has been observed as early as January, as was the case in 1934. Branches continue to flag during the summer and even into the fall of the year. The flagging condition is predominantly in the upper crowns of vigorous as well as less vigorous trees, and many leaders one and a half inches or more in diameter, and four feet or so in length, will oftentimes be killed. (Figure 1). Flagging of terminals is common. The

Insert Figure 1

first evidence of a dying branch is the gradual fading of the needles from base out usually, so that they assume a light pea-green color. The needles gradually droop, turn yellow color and die. The dead needles usually remain intact with the branches for several months, although within a year most of them will have sloughed off. Occasionally some retain dead needles into the following year.

A pine tree that has recently flagged, and particularly one that has flagged heavily, will appear to be worse than it actually is. The tendency is to overestimate the percent of flagged branches as compared to the remaining green ones on the tree and this is probably due to the fact that the yellow flags are so conspicuous against the dark green needle background. One particular tree, located on one of the study plots on the Prescott National Forest, that looked practically dead at the time, was flagged only 66 percent. Records indicate that this tree is recovering.

A critical examination of dying branches, made possible by cutting into them, reveals at least one primary lesion (Figure 2), usually impreg-

Insert Figure 2

nated with pitch, that completely girdles the branch. This lesion commonly exists on the third and fourth internodes, although many have been observed on the other internodes on the twigs up to the sixth. Many partial lesions are in evidence on green branches, and it is believed that some of these may eventually kill the branch when proper conditions exist.

Flagged trees characteristic of the type on the Prescott are by no means restricted to the forests in this region, but have been observed elsewhere in Arizona and New Mexico. Flagging identical in every respect to this has not as yet been found in California, and this may be due to the fact that Pinus ponderosa var. scopulorum does not occur in the pine stands of this state.

HOW THE SCALE, MATSUCOCUS VEXILLORUM, ATTACKS PINE STEMS

In the early spring there will be observed on the stems of ponderosa pine on the Prescott National Forest, small scale bodies (preadults) hidden beneath needle bracts. This stage feeds on the pine branches. Later in the spring adult females emerge from the preadult bodies (Figure 3), migrate,

Insert Figure 3

and finally settle about the nodes of the stems where they secrete wax and lay eggs. The eggs hatch into larvae that crawl onto the pine stems, settle, and commence feeding. Several molts occur during the remainder of the season, and by fall the preadult larvae are produced. The scale overwinters in this stage of development. It is during the larval stages that feeding occurs which results in injury to the pine branches.

For further information pertaining to the seasonal history of this scale, Matsucoccus vexillorum Morrison, the reader is referred to the section on this subject included later on in this bulletin.

PLANT TISSUES SPECIFICALLY AFFECTED BY FEEDING HABITS OF THE SCALE

It is during the larval stages that this scale feeds, and as a consequence histological sections have been prepared to study its feeding habits. On the basis of these histological preparations it appears that the stylets or mouthparts of the scale insect terminate in storage cells of the cortex area, and a photomicrograph of this has been taken (Figure 4). Of

Insert Figure 4

the many hundreds of histological sections made, this one only shows the apparent termination of the stylets into a large cortex storage cell. Other preparations show the stylets penetrated into the epidermal cells and many cases are to be found where they have reached the old cortex area, being apparently cut off beyond this point by mechanical means and not being recovered again in sections of the same series. It also appears that where the stylets have pierced through a cell there has been a coagulating substance formed around the stylet sheath. Brown's experiments⁽⁴⁾ on the feeding

- (4) 1916. Brown, K. B. The specific effects of certain leaf-feeding Coccidae and Aphididae upon the pines. Ann. Ent. Soc. Am. No. 4, 9:414-422.
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of various coccids upon pines indicate that when the stylets are forced into the plant tissue a sheath of saliva is formed about it. According to Carter's work⁽⁵⁾ on the pineapple mealybug this coagulating substance is

- (5) 1933. Carter, W. The spotting of pineapple leaves caused by Pseudococcus brevipes, the pineapple mealybug. Phytopathology, 23:243-259).
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produced by a phytotoxic secretion. In both instances some enzyme or toxic material came from the scale insect, and it is reasonable to assume that this is what takes place in the feeding of Matsucoccus vexillorum Morrison on the pine trees in Arizona.

The kind of food present in these cortex storage cells may be divided into two general types, (1) inorganic substances dissolved in cell sap and readily available for the scale insects, and (2) those insoluble substances which are probably dissolved by enzymatic action from the sucking insects. The first type includes such substances as water, calcium, soluble fats, simple carbohydrates (such as soluble sugar), and possibly some other complicated carbohydrates such as starch. The second type includes substances such as the compound proteins (nucleo), fats, polysaccharides, cellulose and haemicellulose of the cell wall. Sugars, fats and simple proteins or amino acids probably make up the principal diet of this Matsucoccus scale insect.

It has been repeatedly observed that if one will carefully cut beneath an aggregation of feeding Matsucoccus scale on a ponderosa pine branch, even where the scale have settled near the node on the current year's growth, there will usually be a brown spot in evidence, and this is more specifically known as "necrosis". Furthermore, if one will repeat this operation on a normal uninfested current year's growth near the node, no such spot will prevail unless some abrasion has previously taken place. The natural bark plate formation of normal uninfested growth is not greatly extended and will not be confused with necrosis beneath feeding scale. The consistency of these spots associated with an aggregation of scale cannot be ignored. As a consequence of this phenomenon, extensive histological studies have been made. An examination of microscope slide preparations of wood sections showing necrotic areas found in association with Matsucoccus scale shows a very definite internal break-down of cell contents as well as cell wall disintegration (see Figure 5-A). Figure 5-B shows a wood section of normal uninfested current year's growth of ponderosa pine.

Insert Figure 5

RELATION OF SCALE POPULATION TO LESIONS AND FLAGS

Many necrotic areas are produced on stems which are not followed by flagging, and it has been observed that these form only a scar or partial lesion that heals over. However, there are some such necrotic spots that do cause full lesions that completely girdle and kill the twig and this is definitely proven in the discussion that follows.

During the periodic check-up of the flagging of artificially infested ponderosa pine trees on the Wolf Creek, plot 1, it was discovered that a heavy population density of Matsucoccus vexillorum existed on flagged twigs, and that a much lighter infestation occurred on the green infested twigs. As a consequence of this discovery, a more thorough determination of scale population density on flagged and green twigs was made from infestations occurring in the field.

Since it has been already demonstrated by preadult population counts that the largest number of insects occur on the second year's internode (see page 28), it was decided to use this as an index for these determinations. Green and flagged twigs from infested trees were collected at random for microscopic examinations. Data were obtained from a total of 285 individual twigs segregated by internode length, and the tabulated results are presented in Table I.

Insert Table I

The data included in this table show: (1) that the population density of scale insects on flagged twigs is over twice that on green twigs, i.e. the 5 inch flagged internode possesses an average of 53.0 scale, whereas in the same length of green internode only 18.6 scale occurred*; and (2) that

- * It should be taken into account that hundreds of dead scale have sloughed off the internodes of the flagged twigs with dead needles. Only 27 percent of the second internodes on the flagged twigs retained needles, as compared to 80 percent included on those of the green twigs. This fact alone would increase many fold the average number of scale per inch on flagged internodes.
-

flagging contributed to a high mortality of Matsucoccus scale, i.e. the 5 inch class of flagged internodes possessed an average of 48.7 dead scale, whereas in the same class of green internodes only 3.9 dead scale occurred.

TANGLEFOOT BAND STUDIES

Even though it had been demonstrated through actual counts that a large population of Matsucoccus scale was always present on flagged branches, there was still the question as to whether the scale insects were definitely associated with killing lesions. Therefore, it was deemed advisable to initiate experiments along this line, and this was done by applying sticky tanglefoot barrier restrictions to the pine stems prior to scale introductions. Two types of barriers were used, one type consisting of only a thin layer of sticky tree tanglefoot smeared around the stem, and the other type made up of an absorbent cotton base wrapped around the stem and about which was placed a $\frac{1}{2}$ inch strip of scotch tape. (See diagram Figure 6). On top of this scotch tape the sticky

Insert Figure 6

tanglefoot substance was applied, and this was done to prevent the tanglefoot from coming in contact with bark surface and causing burn. The tanglefoot barriers were placed at the extremities of the internodes and these were generally effective in limiting the scale, although in a few instances it was observed that some of the insects escaped onto adjoining internodes. The scale was introduced to the restricted internodes by placing egg masses into small thimble-shaped copper screen baskets, these baskets being securely held to the internode by means of a fine copper wire. This work was done at Prescott, Arizona, during the spring of 1938 and at that time thirty-five (35) trees (16 trees of which were on the Wolf Creek Plot 2, and 19 trees on the Copper Basin Divide Plot 3) were artificially infested in this manner. Twenty-two (22) of these trees had first internode restrictions (Figure 7), and fourteen (14) had the second inter-

Insert Figure 7

nodes restricted by means of the tanglefoot band method. The gross results of these tanglefoot infestations are given in tables 2 and 3.

Insert Tables 2 and 3

During the summer of 1939 fifty (50) of the 1,075 internodes originally infested with scale were cut and taken into the laboratory at Prescott for examination. Each internode was figured or diagrammed to actual size on a piece of drawing paper and measured off into linear inches. The copper baskets and tanglefoot barriers were removed from the internodes and the needles cut off rather short, thus making it possible to observe the infestation of scale under the low power binocular microscope. Preadult scale counts were then made. After the scale counts were completed, the internodes were carefully sliced with a pocket knife so as to determine the exact position of the primary lesion responsible for the death of the twig, (see diagram, Figure 6).

The cotton-scotch tape tanglefoot band restrictions were about forty-two (42) percent more effective than when the sticky tanglefoot substance was used alone. The scale larvae apparently preferred to settle under the cotton bands because it afforded them some protection. As many as 225 preadult scales of Matsucoccus vexillorum have been observed under one of these cotton-scotch tape tanglefoot bands! The results of the scale counts made on the fifty (50) tanglefoot internode restrictions indicate that when there is an average population density of 100 preadult scales per linear inch of stem, with diameters of from $\frac{1}{2}$ to $\frac{3}{4}$ inches, there will be associated with these insects primary lesions that kill the branch, (see diagram, Figure 6). When the scale insects feed evenly around the stem, fewer individuals are required to form a complete lesion.

In nature when populations of Matsucoccus vexillorum scale become great enough to be lethal to the branch, the numbers of feeding preadults are rather evenly distributed on all of the internodes, and primary lesions commonly occur on the third, fourth, fifth and sixth internodes as well as on the younger growth. In the case of the tanglefoot band studies, however, a concentration of scale has been restricted to one portion of the stem sufficiently great to cause death to that particular internode as well as to the younger growth beyond it. The needles immediately behind the primary lesion, within the tanglefoot restrictions, remain alive and green, while those beyond this lesion die. (Figure 8).

Insert Figure 8.

DEMONSTRATION EXPERIMENTS

The first tests to determine the relation of Matsucoccus vexillorum scale to flagging were done during April, 1936, by Dr. Harold Morrison of the Division of Insect Identification, and Dr. A.S. West of the Division of Forest Insects. At that time ten (10) ponderosa pine trees were artificially infested with this scale. The scale insects used for this work were collected from heavily flagged trees in the forest and were introduced to the experimental trees by placing scale egg masses, still intact with the nodes, into small thimble-shaped copper screen baskets and fastening these securely on the twig by means of a fine copper wire, (Figure 9). Dr. Morrison was responsible for

Insert Figure 9

this technique and also for ideas as to how the test should be conducted. A total of 220 twigs were grossly infested, and during the following season (1937) 45.5 percent of these infested twigs flagged. In 1938, five additional twigs on these same trees flagged, and during 1939 four more flagged, thus indicating that as the infestation of scale continues to build up and become great enough, flagging will ultimately result.

In the spring of 1937 the author artificially infested fifteen (15), scale and flag free, ponderosa pines on the Prescott National Forest. On some of these experimental trees the scale egg masses were introduced to the branches by means of a camel-hair brush, while on the remainder the copper screen wire baskets were employed. In the early spring of 1938, before there was much evidence of branch flagging, each infested branch was carefully examined in the field by use of a 10x power hand lens to determine the population density of preadult scales on each branch. Three population density classifications were set up as follows: heavy, medium and light. The results of this artificial infestation work are included in Table 4. The interesting thing about

Insert Table 4

these population forecasts is that such a large percentage (80%) of those branches having heavy infestations of scale flagged, whereas, those having only a light population, or no scale, did not flag at all. The population density of preadult scale affords a convenient indicator for determining whether branches will flag or not. It will be noted from the table that there were many twigs on the experimental trees where only a few, or no scale, became established. This is probably due to the fact that the majority of the trees were infested after the scale eggs had hatched and the young larvae had already moved elsewhere on the infested branches occurring naturally in the forest. Fourteen (14) additional twigs on the experimental trees in this plot flagged during the 1939 season, again substantiating the fact that a continued build-up of scale population ultimately results in branch killing.

During the spring of 1938 it was decided that the most convincing thing to do to prove the definite connection of Matsucoccus vexillorum scale with the flagging of pine branches was to establish some large demonstration plots in which perfectly healthy, vigorous green trees, free of scale and flagging, might be artificially infested with this scale insect. Two experimental plots were laid out on the Prescott National Forest, one (Plot 2) in the Wolf Creek Area, and the other (Plot 3) in the Copper Basin Divide Area. The Wolf Creek plot was, at the time of establishment, in a supposedly flag-free area, although records indicated that some flagging had been observed in this area in years previous. The Copper Basin Divide plot had never, according to the Forest Service records, shown any flagging at all. This plot existed on a divide where winds prevailed in varying intensity throughout the whole year. The trees on this plot were, for the most part, extremely vigorous types. On the Wolf Creek Plot 2, ninety (90) trees were artificially infested with Matsucoccus scale (21 of these trees were given to the Office of Forest Pathology for their culture work), and on the Copper Basin Divide Plot 3, sixty (60) trees were artificially infested. A total of 1,675 individual branches were originally infested with scale, although actual records were taken on only 1,330 branches. Those given to Pathology are not included in this bulletin. Tables 5 and 6 give the results of this artificial

Insert Tables 5 and 6

infestation work. It will be noted from these tables that the percent of flagged branches is not great, although it must be kept in mind that there will no doubt be a continued build-up of the population of scale insects, and when the population becomes sufficiently great, more flagging will result. This has already been demonstrated in the case of the preliminary studies on artificial infestations initiated in 1936 and 1937. Perhaps in time branches, other than those originally infested on these trees in Plots 2 and 3, will flag as a result of scale migrations. Figures 10 and 11 show the extent of flagging on some of

Insert Figures 10 and 11

these experimental trees in the Copper Basin Divide Plot 3.

In the Lynx Creek Plot 4, eighty (80) naturally infested and flagged trees were marked, and 231 twigs, with adult females and egg masses of varying population intensities, were tagged for future observations. The results of this experiment are given in Table 7. It will be noted from this table that

Insert Table 7

it was possible to predict flagging of seventy-two (72) percent of the branches that possessed heavy populations of adult females and egg masses. Using this stage as a criterion in determining whether a green branch will flag during a given length of time is not as exacting as when the preadult scale population is used as an index. This is probably due to the fact that the preadults have completed their development and the full compliment of damage can be ascertained more accurately. In the case of the egg masses, any factor such as predators, or varying climatic conditions, would, no doubt, have a deterrent effect as to the ultimate population of scale on a branch.

NATURAL CONTROL

Although quantities of branches heavily infested with Matsucoccus vexillorum scale were held in the insectary for parasite and predator recovery, there was but little gained by this experiment. Only two predators, a ladybird beetle, Scymus sp., and a green lacewing, Chrysopa sp., were recovered. These predators were only occasionally observed in nature and it was quite evident that they played a minor part in the control of this scale insect.

The principal governing natural control factor is the flagged branches on which many hundreds of scale insects have settled. On the basis of extensive scale population counts on both flagged and green twigs (see Table I) it is reasonable to assume that once the scale population has built up to the extent that the branch dies, the scales, as a consequence, perish also. Out of a total of 5,669 scales counted on flagged twigs, 5,302 were dead. On the green twigs the condition is just the reverse. Out of 2,328 scales counted only 511 preadults were dead, and this appears to be nothing more than the natural mortality of the insect.

EFFECT OF FLAGGING UPON PINE TREES

Flag counts made during the summer of 1938 and 1939, on the eighty (80) experimental trees on the Lynx Creek Plot 4, indicate that trees heavily flagged one year will flag lightly the following year. For example, on experimental tree number 5 in this plot, one hundred and fifty-two (152) flags were counted in 1938, while only twenty (20) flags were observed during the summer of 1939. This shows a decrease in flagging of approximately eighty-six and eight-tenths (86.8) percent. Other trees in this plot show about the same percent decrease in flagging, although the general average for all trees was not this great. On some of the trees in this plot there was a slight increase in flagging during 1939.

Evidence, as a result of field observations on the Prescott National Forest, indicates that flagging causes no serious permanent damage to the timber stands as a whole. Although certain areas have shown considerable damage in the past, these same areas now show but little evidence that individual trees will succumb to the scale damage. While no specific studies have been made by this Bureau on growth characteristics, it is highly probable that growth increment is decreased following periods of heavy flagging. If such decreases in tree growth do occur as a result of a season of heavy branch flagging, there appears to be a very rapid recovery of the trees as is evidenced by the much extended current growth on the branches in the following year. For these reasons any attempt directed toward the control of this scale insect may be considered as impractical.

SEASONAL HISTORY OF THE SCALE, MATSUCOCUS VEXILLORUM MORRISON

The information regarding the seasonal activities of this insect and its effects upon the host tree were secured both by field observations and insectary controlled rearings in the vicinity of Prescott, Arizona. A preliminary survey of ponderosa (scopulorum) pine areas in Arizona and New Mexico and collections made by the office of Forest Pathology have served as the basis for known distribution of this insect.

Distribution and Hosts

The geographical range of Matsucoccus vexillorum Morrison appears to be general throughout the forested areas of Arizona and New Mexico. Definite locality records exist showing that it is present on the Prescott, Coconino, Sitgreaves, Apache, Gila, Coronado, Cibola and Santa Fe National Forests (see accompanying map, Figure 12).

Insert Figure 12

The only known host of this Matsucoccus scale is Pinus ponderosa var. scopulorum Englemann. It is apparently quite specific in its host preference as no specimens have been collected from any other species of the genus Pinus.

Adult Female Scale.

Description. In general appearance the adult female scale is rather robust and elongate with the posterior end of the body somewhat broader, (see Figure 3). This stage is approximately $3/16$ of an inch in length, has paired leg appendages, is brown in color, and continually manipulates the 9-segmented antennae, feeling its way cautiously over the wood surface. No functional mouthparts are present, and as a consequence feeding does not take place during this stage.

Habits During early spring, usually April, of each year, many hundreds of these brown adult females (see pictorial plate, Figure 3) may be observed shoving their way out of the overwintering intermediate or pre-adult bodies. Their actions are sluggish and at first it appears as though they might settle any place on the branch. They may migrate several feet before they finally settle down. It will soon be noted that they definitely prefer to settle at the nodes, principally on the underside, crowding against and on top of one another in large numbers (Figure 13). Occasionally they

Insert Figure 13

will be found settling on some twig killed by tip moth or any sort of crack or crevice that affords them ample protection. Soon after settling wax is profusely secreted, and as the eggs are extruded, the abdomen is gradually retracted or withdrawn into the thoracic (forepart) region of the adult female, thus forming a kind of invaginated marsupium. Figure 3 shows a rather incompletely invaginated pocket. It appears as though the whole body has been modified for the reproductive function. By the time the eggs are laid, and this is usually within 4 or 5 days, the secreted wax filaments are so intertwined that practically the entire body of each female is covered, and when these females congregate about the nodes they present the appearance of small tufts of cotton. Eggs are to be found in the marsupium as well as in these waxy secretions.

Population counts of the mature females after they have settled in these cottony masses indicate that they apparently prefer to settle about the nodes rather than on the internodes. Out of 199 green branches examined, only 6 percent of the internodes were found to possess adult females. The actual node counts are tabulated below:

<u>Node</u>	<u>Nodes examined</u>	<u>Females counted</u>	<u>Average population per node</u>
1	199	3,110	15.63
2	199	5,670	28.49
3	199	462	2.32
Total	597	9,242	15.48

The above figures indicate that the adult females prefer to settle on the second node rather than on the first or third, and this may possibly be explained by the fact that the insects migrate just prior to the time the current year's bud starts growing, and that until this takes place and the needles become full grown, the available space for them to settle on the first node is apparently more limited than on the second node. The tendency is for them to work their way out as far toward the tip as possible and still have a node about which they may settle.

Adult Male Scale

Description. The minute winged adult male scales are seldom seen in nature. They possess the characteristic two wings and the long, white, waxy anal filaments. The males are extremely fragile, scarcely 1/16 of an inch in length, and as a consequence it is difficult to see them with the unaided eye. (See pictorial plate, Figure 3).

Habits. The adult male scales emerge during early spring (usually April when the adult females are in evidence) from the intermediate or pre-adult stage. Wings are developed later and these winged males may be seen walking over the pine stems, apparently using the wings as a sort of balance. Flights of the winged males have not been seen by the author, and this is no doubt due to their relative inconspicuousness. Copulation with the migrating females was observed, however, and it can be assumed that fertilization takes place during this migrating period.

The Eggs

Description. The eggs of this scale insect are found within the marsupium and waxy secretions of the adult female. The individual egg is exceedingly small and is practically invisible to the unaided eye, although the egg mass itself is quite conspicuous. An average of 167 eggs are laid by each adult female scale. The eggs are bean shaped in appearance (see Figure 3) and are first lemon yellow, but as they incubate become a deep orange-yellow color. Prior to hatching, each egg presents two distinct eye spots, and these represent the eyes of the developing larva within.

Incubation period. The incubation period of the eggs of this species of Matsucoccus will vary from 12 to 23 days depending primarily upon climatic conditions. Hatching takes place usually during the month of May in the vicinity of Prescott (altitude 5,500), although at higher altitudes the incubation period may be retarded for several weeks.

First Stage Larvae

Description. The first stage larvae are oval shaped, possess leg appendages, and are but little larger than the eggs themselves. (See Figure 3). In order to see them clearly it is advisable to use a hand lens or microscope. They appear lemon yellow at first, although as they develop they will turn darker yellow-orange.

Habits. These larvae are quite active, although they soon settle under the thin layers of bark on the stem and many are to be found under the bract enclosing the needle base. Feeding takes place during this stage. Prior to the first molt there appears to be a quantity of wax secreted from the posterior portion of the body of the insect. This wax appears to be rather short filaments as contrasted with the long filaments secreted by the adult females. The first molt* occurs usually within 38 to 44 days, depending

*There has been much discussion concerning this molt giving rise to an appendage second stage larva. However, experimental evidence at hand indicates that such is the case.

upon climatic conditions, after the young first settle. This molt occurs during the latter part of June or the first part of July in the vicinity of Prescott.

Second Stage Larvae

Description. The early second stage larvae resemble the first stage except that they are somewhat larger. However, they are still quite small and it is necessary to use a hand lens in order to magnify the insects enough to really see them. As far as can be determined, the leg appendages, antennae and spiracles (breathing pores) are apparently identical morphologically with those of the first stage larvae.

Habits. The second stage larvae migrate but a little distance from their previous feeding quarters and often settle practically in the same spot. They do, however, show a decided preference and usually settle under the bract enclosing the needle base, and occasionally some are to be found in cracks and crevices of the bark layers. Once the second stage larvae settle, feeding commences. Although the early second stage larvae resemble the first stage, it is but a short time after settling (usually 6 or 8 days) that they commence swelling in the anterior portion of the body so that they rapidly assume a pyriform outline. They continue to grow and swell until finally the leg appendages are no longer of any use to the insects. The second molt occurs usually during the middle or latter part of August in the Prescott vicinity - approximately 50 days after the first molt.

Intermediate or Preadult Stage Larvae.

Description. The third, intermediate or preadult stage larvae are apodous (without legs) and it will be readily observed from the stained microscopic preparations that there has been a marked change in the spiracles as compared to these structures as they exist in either the first or second stages. The preadults of the female sex are stout, nearly circular, and the derm is more or less distinctly chitinized. According to a letter from Dr. Harold Morrison there is but a slight differentiation between the male and the female in this preadult stage, and the author was unable to distinguish them. When fully mature, the female preadult is about the size and shape of 5 or 6 gauge bird shot, and is readily discernible with the naked eye. By far the greater number of these are to be found under the bract enclosing a needle base. (Figure 14).

Insert Figure 14

Habits. The second molt giving rise to this preadult stage represents a metamorphic change in which the second stage derm finally ruptures in the anterior part (see Figure 3), and for some time the early preadult stage larvae are almost completely enclosed within this derm. Unless stained microscopic preparations are made at intervals during the scale insect's development, the new stylet or mouthpart formation that takes place prior to each molt will occur unobserved. As a matter of fact the early splitting of the second stage derm would likewise pass without notice unless the microscopic preparations are made every few days. As the preadult grows, the second stage derm continues to split until finally the appearance is that of a derm-cup that encloses only the lower portion of the preadult stage. This derm-cup will oftentimes slough off by the time the insect has attained the fully matured intermediate or preadult stage.

Since the preadults are apodous they are forced to remain in the same place where the second stage larvae settled. No preadults are to be found on the current year's growth, with the possible exception of a very few near the first node. This may be explained on the basis that by the time the second stage larvae settle, the current growth has extended but very little and what area is available for feeding is just that around the first node. As a consequence, by far the greater number of preadults settle on the second internode, and extensive population counts have been made to substantiate this statement. The preadults are less frequent on the third internode, and are rarely observed on the fourth internode unless the tree is extremely heavily infested. On one particular green second internode, 5 inches long and .25 inches in diameter, a total of 104 preadults were counted, although the average for this size green internode was but 40. The average number of preadults for the same size green internode on the third and fourth internodes is approximately 20 and 13 respectively. On flagged twigs the scale population per internode is two or three times as much as on infected internodes or green twigs.

- 2 -

The preadults, like the first and second stage larvae, also possess stylets or sucking mouthparts, and it may be assumed that during the pre-adult stage the most feeding occurs. It is during this stage that the scale insect passes the winter. The preadults usually do not attain their maximum size until some time in February of the following year (see seasonal history plate, Figure 3), and it is not until during April and May that the adult males and females emerge from these overwintering bodies.

SUMMARY

Forest Service correspondence files indicate that complaints pertaining to branch killing or "flagging" of Pinus ponderosa var. scopulorum on the Prescott National Forest in Arizona have come in at rather definite intervals throughout the past 15 or 20 years.

Historically, the actual cause of this tree disturbance was unknown for many years. In May, 1935, the presence of a margarodid scale insect, Matsucoccus vexillorum Morrison, was discovered on branches of pine trees at Prescott, Arizona.

The branch flagging of the pines on the Prescott National Forest is usually first noticeable in early spring. The needles fade to a light pea-green color, gradually droop, and finally turn yellow colored and die.

When dying branches are cut into, there will be observed at least one primary lesion, usually impregnated with pitch, that completely girdles the branch.

On the basis of histological preparations, it has been noted that this scale insect obtains its food from storage cells of the cortex area.

There is a necrosis of plant cells produced by the feeding activities of aggregations of this scale insect. Histological preparations show an internal breakdown of the cell contents and cell wall disintegration.

When there is an average population density of one hundred (100) preadult scales per linear inch of stem, with diameters of from $\frac{1}{8}$ to $\frac{3}{4}$ inches, there will be associated with these insects primary lesions that kill the branch. When the scale insects feed evenly around the stem, fewer individuals are required to form a complete killing lesion. Flagging is the result, however, of a generally high population density of Matsucoccus scale.

Artificial infestation experiments initiated during the spring of 1936, 1937 and 1938 resulted in a high percentage of flagged twigs where heavy populations of scale became established. Artificially infested twigs may flag several years later when the population of scale becomes great enough to be lethal to the branch.

The principal governing natural control factor is the killed, or flagged branches, on which many hundreds of scale insects have settled, and this accounts for the fluctuations of flagging throughout successive years.

Evidence, as a result of field observations on the pine forests in Arizona and New Mexico, indicates that flagging causes no serious permanent damage to the timber stands as a whole. Although certain areas have shown considerable damage in the past, these same areas now show but little evidence that individual trees will succumb to the scale damage. Any attempt directed toward the control of this scale insect may be considered as impractical.

The only known host of this scale insect is Pinus ponderosa var. scopulorum Engelman. Matsucoccus vexillorum Morrison is rather generally distributed throughout the forested areas of Arizona and New Mexico.

Seasonal life history records of Matsucoccus vexillorum Morrison scale indicate that there is a motile adult female and a winged male emerging during early spring. The adult females settle at the nodes of the branches, secrete wax and lay eggs. There are two appendage-stage larvae developed during the summer, and an intermediate or apodous preadult scale formed in the fall that overwinters on the pine branches under the bract enclosing the needle base. A year's time is required for this species of Matsucoccus scale to complete its life history.

TABLE I.

Matsucoccus Preadult Random Population Counts
Grouped by 1936 Internode Lengths.

Flagged Twigs				Green Twigs			
:Average	:Average	:	Scale pop. on 1936 internode:	:Average	:Average	:	Scale pop. on 1936 internode
No. twigs: length	: diameter	:		No. twigs: length	: Diameter	:	
involved: internode: internode	:	:	Living: Dead: Total: Average	involved: internode: internode	:	:	Living: Dead: Total: Average
:(inches) : (inches)	:	:	:	:(inches) : (inches)	:	:	:
20 : .9	: .4	:	21 : 366: 387 : 19.3	28 : 1.2	: .3	:	211 : 67 : 278 : 9.92
20 : 2.1	: .3	:	41 : 559: 600 : 30.0	28 : 2.0	: .2	:	345 : 83 : 428 : 15.2
42 : 3.0	: .3	:	101 : 1309: 1410 : 33.5	31 : 3.0	: .3	:	359 : 109 : 468 : 15.1
22 : 4.0	: .3	:	67 : 732: 799 : 36.3	12 : 4.0	: .3	:	185 : 55 : 240 : 20.0
12 : 5.0	: .5	:	51 : 585: 636 : 53.0	19 : 5.0	: .5	:	280 : 75 : 355 : 18.6
15 : 6.0	: .5	:	43 : 856: 899 : 59.9	13 : 6.0	: .5	:	220 : 40 : 260 : 20.0
4 : 7.0	: .5	:	4 : 368: 372 : 93.0	4 : 7.0	: .6	:	57 : 27 : 84 : 21.0
4 : 8.0	: .5	:	18 : 302: 320 : 80.0	1 : 8.0	: .5	:	22 : 4 : 26 : 26.0
1 : 9.0	: .3	:	1 : 40: 41 : 41.0	2 : 9.0	: .4	:	40 : 21 : 61 : 30.5
3 : 10.0	: .8	:	20 : 185: 205 : 68.3	4 : 10.0	: .7	:	98 : 30 : 128 : 32.0
		:				:	
		:				:	
Total 143		:	367 : 5302: 5669 : 39.6	142		:	1817 : 511 : 2328 : 16.3

TABLE 2

ARTIFICIAL INFESTATION EXPERIMENT
TANGLEFOOT BAND STUDIESPrescott National Forest
Demonstration Plot 2 - Wolf Creek Area

(First Internode (1937 Growth) Restrictions)

Crown class	Number Trees Involved	Average Height in Feet	Average Diameter in Inches	Number Internodes Infested	Number Internodes Flagged	Percent of Internodes Flagged
Co-Dominant	3	17.3	3.4	93	34	34.6
Intermediate	7	10.4	2.4	108	39	36.1
Totals and Averages	10	12.5	2.6	206	73	35.5

(Second Internode (1936 Growth) Restrictions)

Dominant	1	28.0	10.9	20	10	50.0
Co-Dominant	6	18.8	6.0	89	5	5.6
Totals and Averages	7	16.1	5.1	109	15	13.7

TABLE 3

ARTIFICIAL INFESTATION EXPERIMENT
TANGLEFOOD BAND STUDIESPrescott National Forest
Demonstration Plot 3 - Copper Basin Divide Area

(First Internode (1937 Growth) Restrictions)						
Crown class	Number Trees Involved	Average Height in Feet	Average Diameter in Inches	Number Internodes Infested	Number Internodes Flagged	Percent Internodes Flagged
Dominant	1	13.0	7.6	82	45	54.8
X(Orchard)	6	9.9	2.5	261	69	26.4
Co-Dominant	3	16.0	4.0	169	56	33.1
Intermediate	1	11.0	2.5	7	4	57.1
Reproduction	1	4.0	.4	3	3	100.0
Totals and Averages	12	11.7	3.1	522	177	33.9
(Second Internode (1936 Growth) Restrictions)						
X(Orchard)	2	14.0	3.7	112	32	28.5
Do-dominant	2	16.5	4.3	55	11	20.0
Intermediate	3	16.6	3.8	71	12	16.9
Totals and Averages	7	10.5	3.9	238	55	23.1

TABLE 4

ARTIFICIAL INFESTATION EXPERIMENT
(on 15 Ponderosa Pines)
Prescott National Forest
Demonstration Plot 1 - Wolf Creek Area

Population Density Preadults Established	Number Twigs Infested	Number Twigs Flagged	Percent Twigs Flagged
None	88	0	0
Light	16	0	0
Medium	14	5	35
Heavy	30	24	80
Totals and Averages	150	29	19.3

TABLE 5

ARTIFICIAL INFESTATION EXPERIMENT

Frencott National Forest
Demonstration Plot 2 - Wolf Creek Area

Crown class	Number Trees Involved	Average Height In Feet	Average Diameter in Inches	Number Branches Infested	Number Branches Flagged	Percent Branches Flagged
Dominant	7	20.0	5.7	113	46	40.7
Co-Dominant	34	12.2	2.7	380	140	36.8
Intermediate	22	11.5	2.1	150	53	29.4
Suppressed	1	8.0	1.6	6	5	83.3
Reproduction	5	4.3	.4	23	8	34.7
Totals and Averages	69	12.1	2.8	702	252	35.8

TABLE 6

ARTIFICIAL INFESTATION EXPERIMENT

Prescott National Forest
 Demonstration Plot 3 - Copper Basin Divide Area

Crown class	Number Trees Involved	Average Height in Feet	Average Diameter in Inches	Number Branches Infested	Number Branches Flagged	Percent Branches Flagged
Dominant	10	24.8	7.7	191	95	49.7
X (Orchard)	12	10.5	2.6	108	55	50.9
Co-Dominant	16	16.8	4.1	191	99	51.8
Intermediate	17	15.7	3.1	127	77	60.6
Suppressed	1	11.0	1.9	3	3	100.0
Reproduction	4	4.6	.5	8	7	87.5
Totals and Averages	60	16.0	3.8	628	336	53.5

TABLE 7

POPULATION DENSITY EXPERIMENT ON 80 NATURALLY INFESTED PINE TREES

Prescott National Forest
Demonstration Plot 4 - Wolf Creek Area

Population Density of Adult Females	No. Branches Tagged	No. Branches Flagged	Percent Branches Flagged
Heavy	25	18	72
Medium	77	30	38.9
Light	129	50	38.7

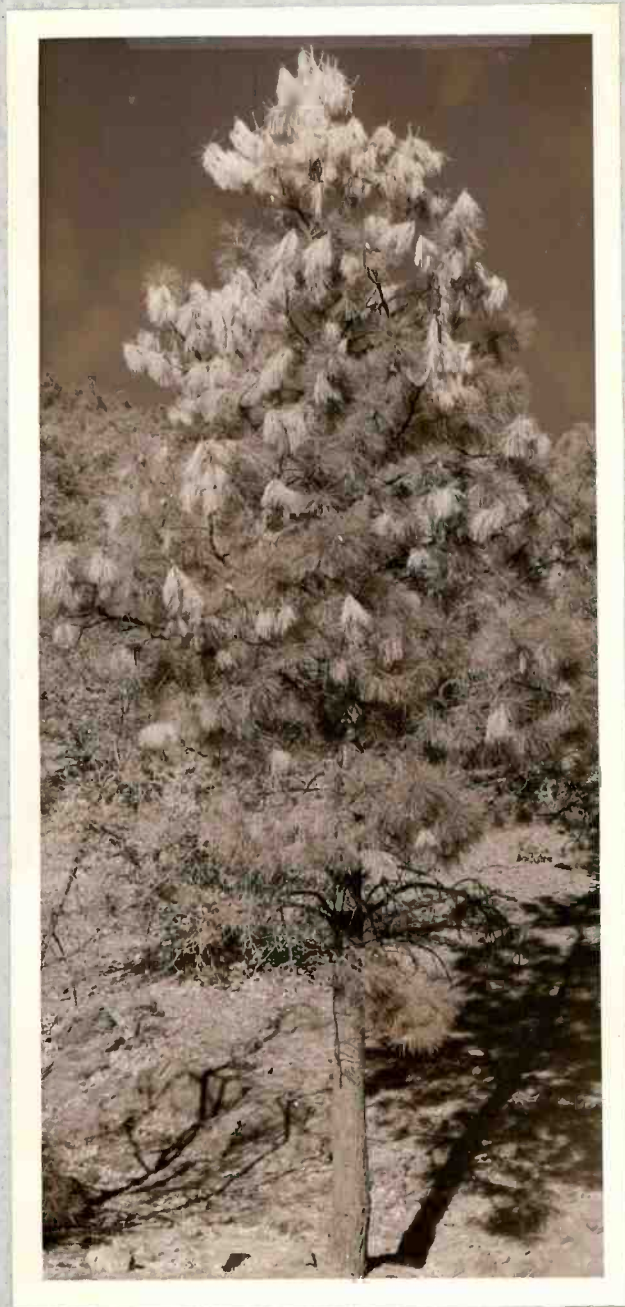


Figure 1. A heavily branch killed or flagged ponderosa pine on the Prescott National Forest in Arizona. A dying branch is first evidenced by a gradual fading and drooping of the needles. The needles finally turn a yellow color and die.

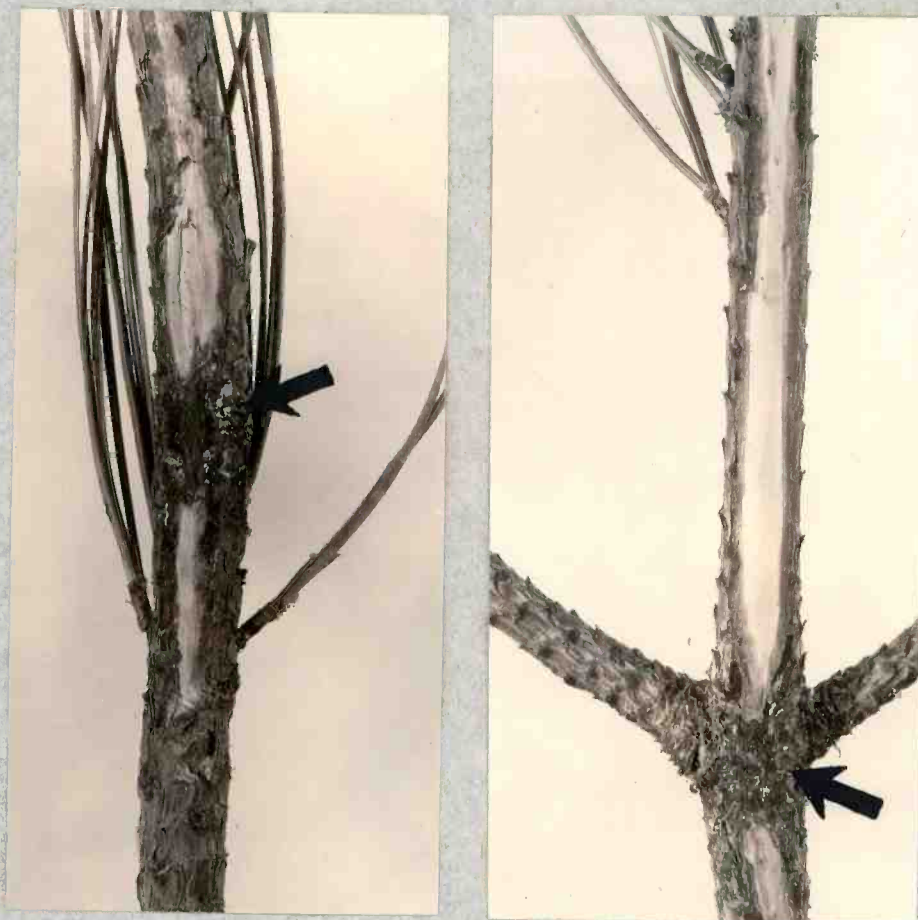


Figure 2. Resined areas or lesions are caused by feeding Matsucoccus scale and these eventually kill the pine branch. Black arrows point to these lesions. Photo by J.E. Patterson.

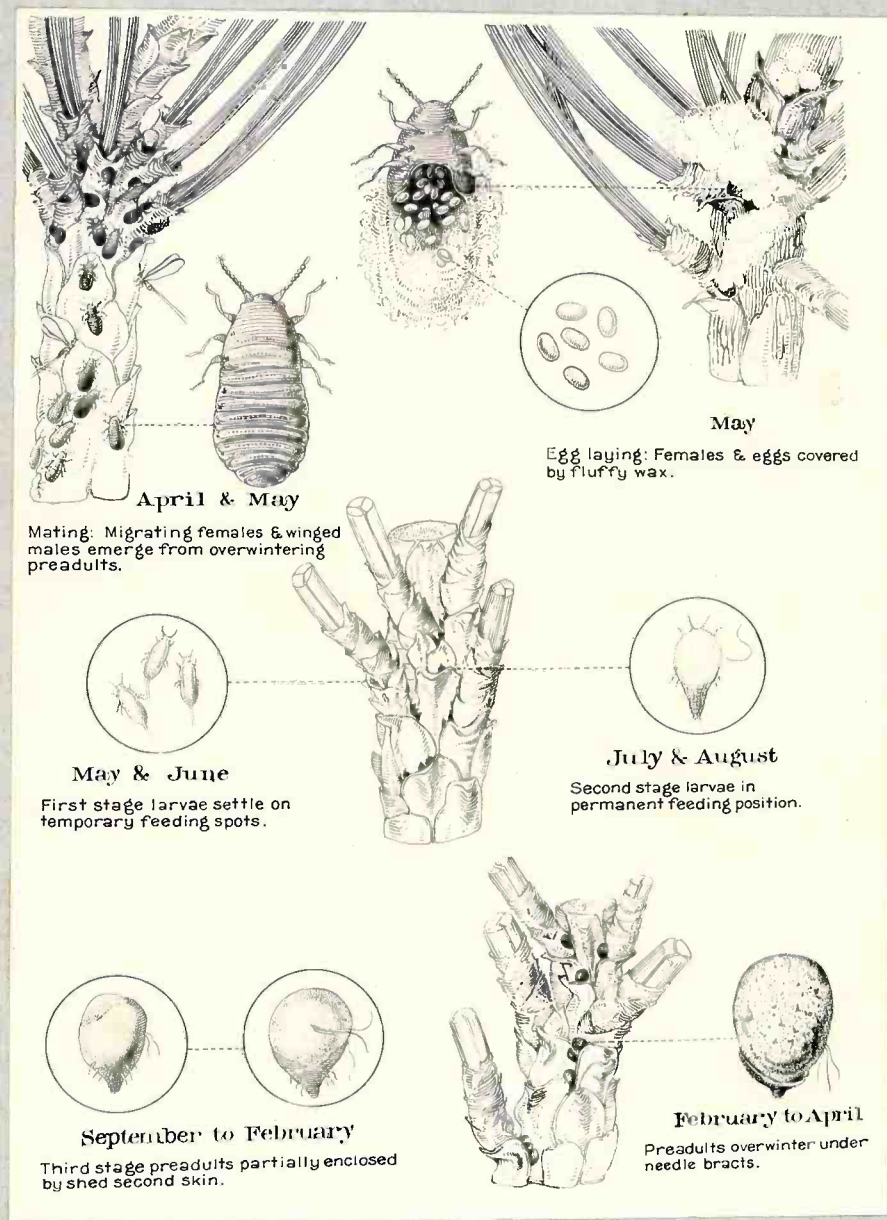


Figure 3. Seasonal history pictorial plate of Matsucoccus vexillorum Morrison.

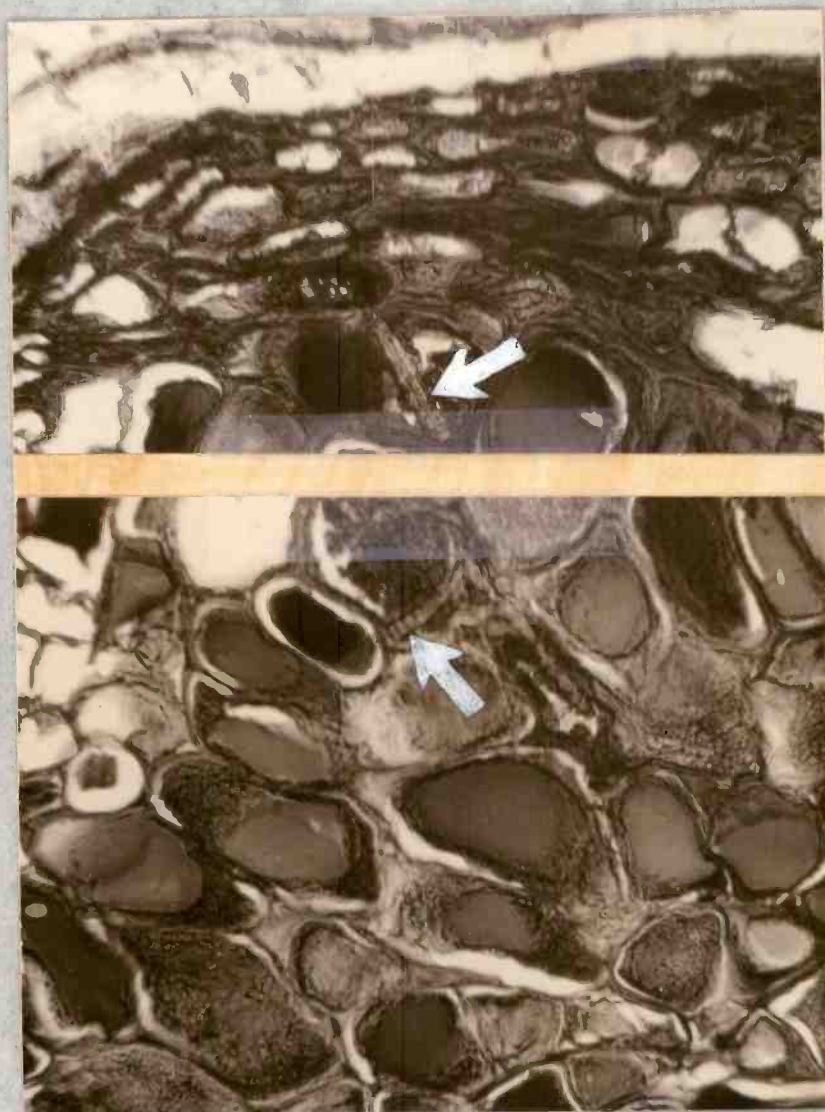
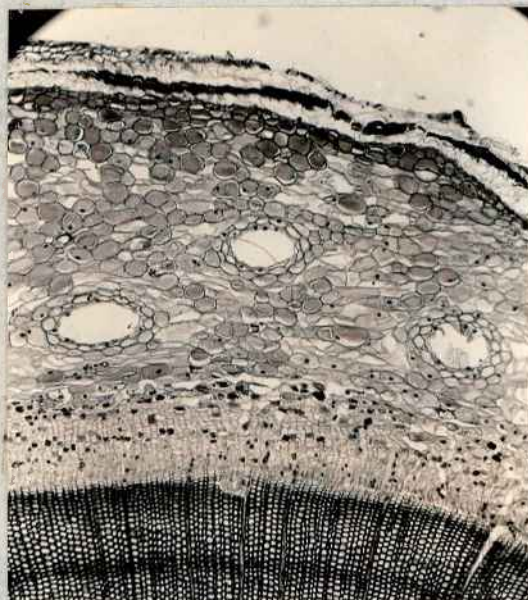


Figure 4. Stylets or mouthparts of Matsucoccus vexillorum Morrison apparently terminate in storage cells of the cortex area. White arrows indicate position of stylets. Photo by J.E. Patterson.



A



B

Figure 5. A. Histological preparation of scale infested current year's growth of ponderosa pine. There is an internal break-down of cell contents as well as cell wall disintegration beneath aggregations of feeding scale. This wood section shows the necrosis (N) directly beneath the scale insect (S).

B. A wood section of normal uninfested current year's growth of ponderosa pine. Note particularly that the bark plate formation is extended but very little in this young growth. Photos by J. E. Patterson.

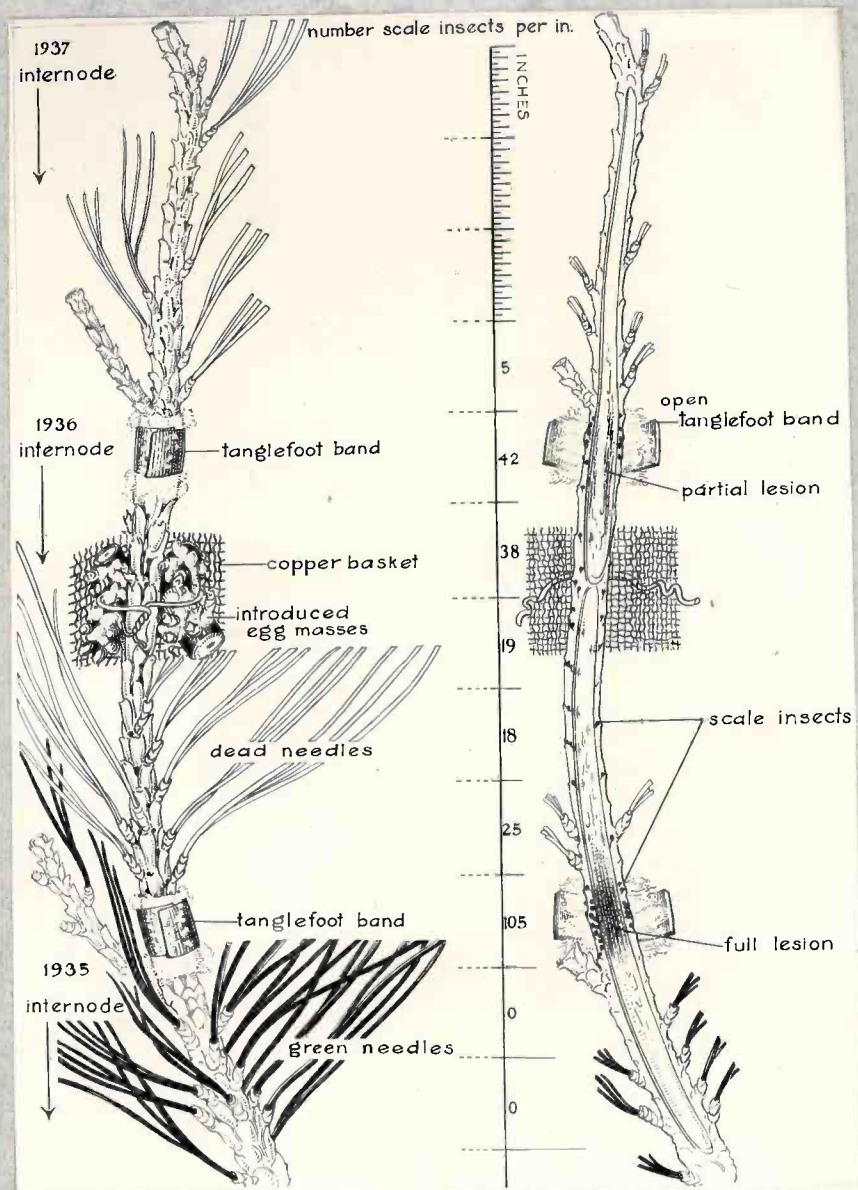


Figure 6. Cotton-scotch tape tanglefoot bands were used to restrict *Matsucoccus vexillorum* scale to various internodes on the pine branches. The scale insects were introduced to the restricted internodes by placing egg masses into copper screen baskets, these baskets being held securely to the internodes by means of a fine copper wire. The tanglefoot barriers were generally effective in limiting the scale to the internodes. When there was an average population of 100 preadult scales per linear inch of stem, with diameters of from $\frac{1}{8}$ to $\frac{3}{4}$ inches, there would be associated with the insects primary lesions that killed the branch. When the scale insects feed evenly around the stem, fewer individuals are required to form a complete lesion.



Figure 7. This experimental tree, number 37, on the Copper Basin Divide Plot 3, near Prescott, Arizona, had tanglefoot band restrictions applied to first internodes (1937 growth) only. Fifty-two (52) percent of the first internode scale restrictions on this tree developed full lesions that resulted in typical flags.



Figure 8. Close-up of two 1937 growth (first internode) cotton-scotch tape tanglefoot band scale restrictions. Note particularly that the needles beyond the tanglefoot band are dead, while those immediately behind it are still alive.



Figure 9. Small thimble-shaped copper screen baskets were used to carry out the artificial infestation work. Hundreds of adult females with eggs enclosed in the waxy secretions were placed in the copper baskets, and these baskets were fastened securely on the twig by means of a fine copper wire. White arrows indicate the position of three of these baskets.



Figure 10. Tree number 10, on the Copper Basin Divide Plot 3, artificially infested with Matsucoccus vexillorum scale during the spring of 1938. Eighty-two (82) percent of the infested branches on this tree flagged during the 1939 season. The remaining green infested branches should flag sometime later when the populations of scale become great enough to be lethal to the stems.



Figure 11. Every artificially infested branch on this tree, number 21, on the Copner Basin Divide Plot 3, flagged during the 1939 season. The tree will most likely recover even though there has been such a severe foliage loss as this. The artificially infested branches on tree number 29, shown in the background, likewise flagged 100%.

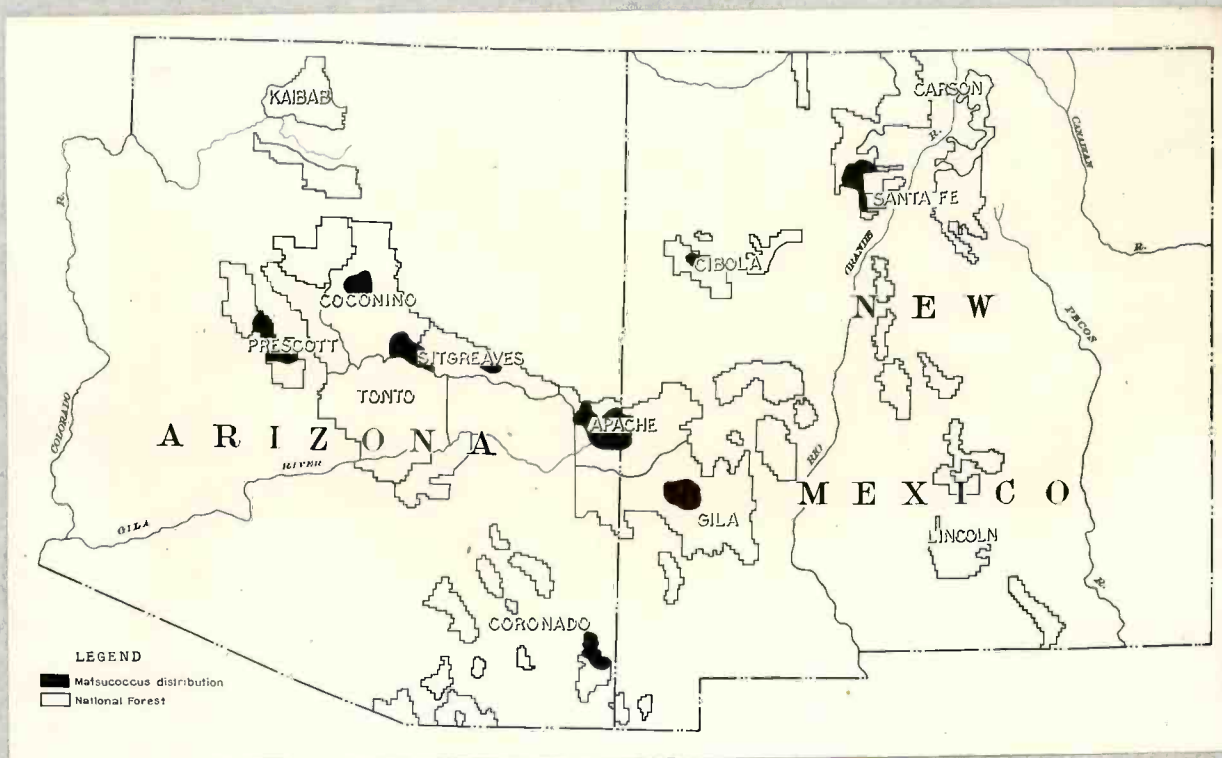


Figure 12. Geographical range of *Matsucoccus vexillorum* Morrison. The insect undoubtedly occurs outside the limits indicated on the above map, but no careful survey or collections have been undertaken in the adjacent regions.



Figure 13. Adult females and egg masses of Matucoccus vexillorum Morrison congregated on the underside of a pine branch about a node. Greatly enlarged. Photo by F. R. Schroeder, formerly with Forest Pathology.



Figure 14. Preadults are found under the bract enclosing a needle base. Greatly enlarged. Photo by F. R. Schroeder, formerly with Forest Pathology.